

# **Stratified Flow Over Topography and Internal Solitary Waves**

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## **LONG-TERM GOALS**

Our long term goal is to use measurements of time varying stratified flow past topography to develop robust models of the relevant processes, including establishment of the high drag state, the role of boundary layer separation, friction and entrainment, and the generation, propagation and dissipation of internal solitary waves.

## **OBJECTIVES**

Our objectives are to analyze the behavior of controlled flows in the neighborhood of a variety of topographic features, in channels and in the open ocean, using both measurements and models, so as to understand the relevant dynamics.

## **APPROACH**

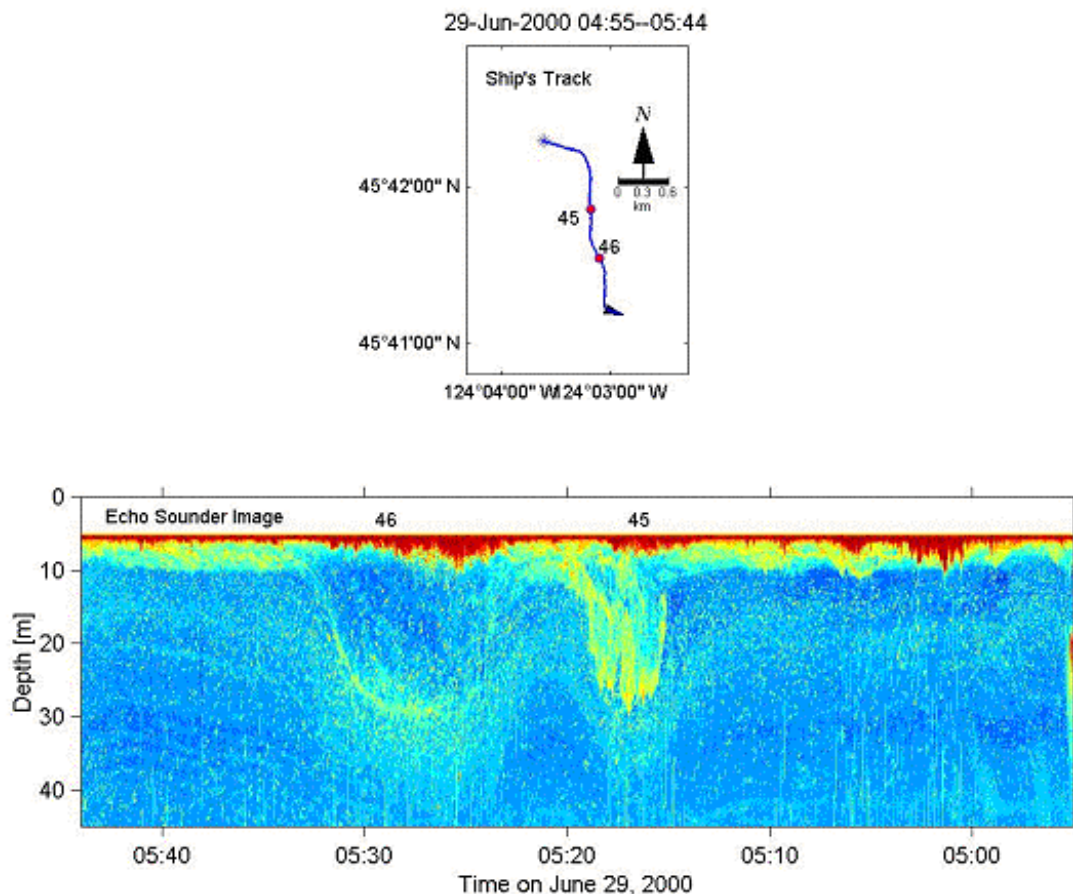
We have carried out observations of both tidally forced and density forced controlled flows using ship based and moored instrumentation. The observations have been acquired over the Oregon shelf, where we studied flow over a bank and the generation and propagation of internal solitary waves, in Haro Strait, where we have looked at the consequences of flow separation from a headland, in Knight Inlet where we have tracked the behavior of strongly forced flow and the transition to the uncontrolled state, and in the Bosphorus where there is an exchange flow. We combine ship based observations using towed sensors, ADCP and acoustic imaging, with moored instruments. Our modeling efforts are focused on identifying key processes rather than achieving detailed simulations, and typically use layered representations, but include effects of friction and entrainment.

Key individuals participating in the work:

- D M Farmer is an physical oceanographer, is the principal investigator responsible for project design and analysis

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- S Vagle is an acoustical oceanographer responsible for implementation of acoustical systems and analysis
- C Garrett at the University of Victoria is a collaborator who has contributed to development of theoretical models.
- L Armi is a physical oceanographer from Scripps Institution of Oceanography who has participated in field experiments and analysis.
- J Moum is a physical oceanographer at Oregon State University with whom we are collaborating in our study of internal solitary waves over the Oregon Shelf.
- B Baschek is a graduate student at the University of Victoria who is studying strongly forced flows and their consequences, especially for air entrainment.
- F Gerdes is a graduate student at the University of Victoria who is studying two-way exchange flow in the Bosphorus.



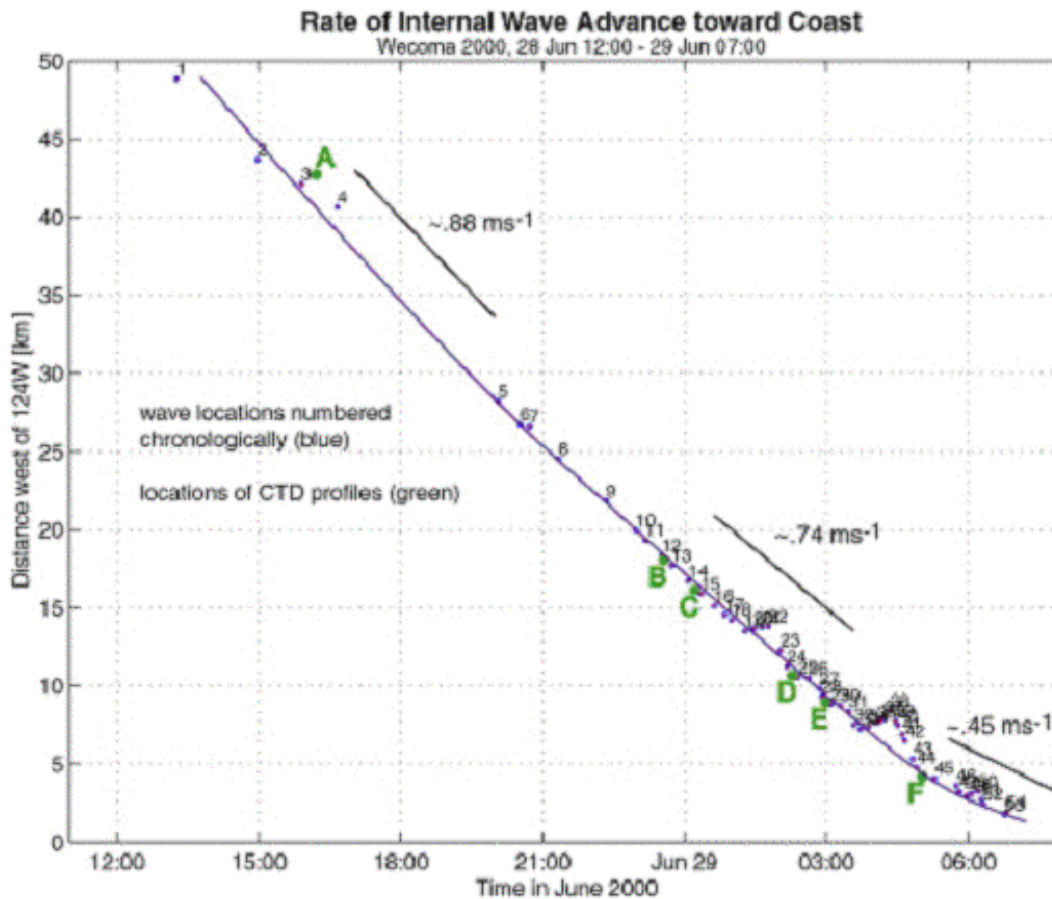
***Figure 1a Acoustic image of internal solitary wave observations 45/46 over the Oregon continental shelf, High backscatter near the surface is due to the presence of bubbles, which are occasionally drawn down into the waves; deeper in the water column back scatter is enhanced by temperature microstructure.***

## **WORK COMPLETED**

This year we completed our analysis of strongly forced flow over a sill and addressed an issue of the interpretation of observations in the light of some prior numerical modeling efforts that fail to properly account for effects due to boundary layer separation. An analysis of stratified flow past a headland was completed. Observations of internal solitary waves over the Oregon continental shelf were analysed so as to determine their evolution under the influence of changing stratification, current and water depth. In order to prepare for a forthcoming Oregon shelf study, a small rubber boat has been fitted with acoustic and other instrumentation to assist in detailed examination of the wave properties, and this boat has been tested in a field study in Knight Inlet. Data acquired in the Bosphorus has been analyzed to reveal the consequences of friction and entrainment. A two-layer model which explores the consequences of these effects on controlled flows has been developed.

## **RESULTS**

1. Our observations of internal solitary waves over the Oregon Shelf, show how they decelerate as they move inshore, under the influence of dissipation and environmental factors (Figure 1).
2. Our studies of the transition of strongly forced flows over a sill show the way in which control may be lost over the sill crest, a result which has been successfully compared with layered models as shown in Figure 2 (from Armi & Farmer, 2001).
3. A controversy over the mechanism by which stratified flow over topography makes the transition to the high drag state, has been shown to result from a failure of numerical models to properly account for boundary layer separation, thus clarifying the role of processes omitted from the models (Farmer & Armi, 2001).
4. It has been shown that entrainment in two layer flows tends to push the flow towards the controlled state, a mechanism of importance in exchange flows such as occur in the Bosphorus (Gerdes, Garrett & Farmer, 2001).
5. Separation of flows past headlands have been shown to lead to three-dimensional effects that can result in greatly enhanced turbulence and mixing (Farmer, Pawlowicz and Zhang, 2001). Figure 3 shows our vessel within the turbulent zone, along with observations of bubble distributions and vertical flow speeds. Our observations point to the enhancement of turbulence through vortex stretching associated with baroclinic tilting of the separated flow.



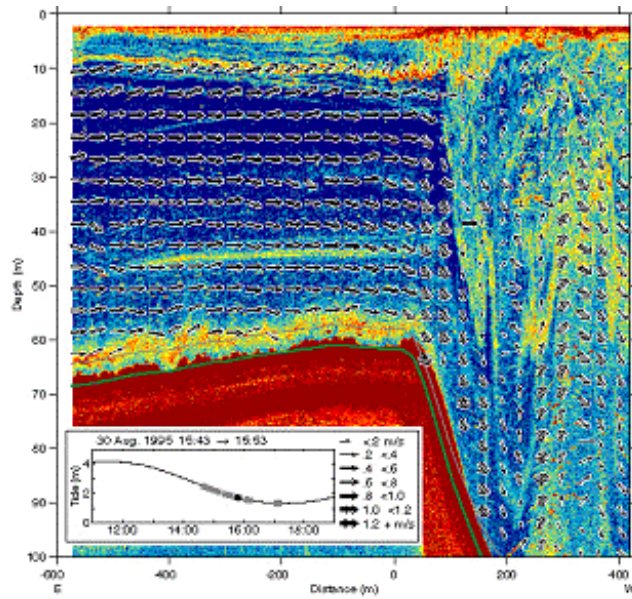
*Figure 1b. Positions of the leading edge of the waves during their propagation across the shelf, illustrating their progressive deceleration as they move inshore.*

## IMPACT/APPLICATIONS

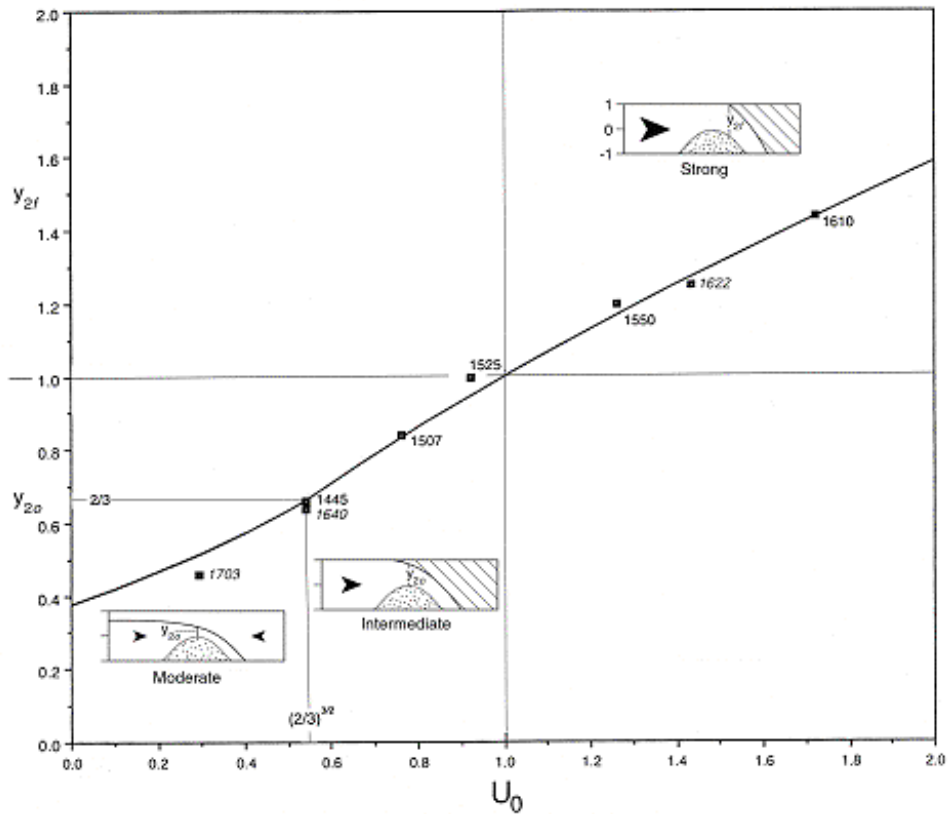
These results contribute to our ability to predict flows in stratified coastal environments, especially in the presence of topography and tidal or estuarine forcing, by demonstrating the underlying mechanisms that have to be incorporated in robust fluid dynamical models.

## RELATED PROJECTS

J Moum's ONR funded studies of topographic flows over the Oregon Shelf; M Gregg's studies of flow in the Bosphorus; L Armi's studies of instability and related phenomena in stratified flows.



**Figure 2a** Image of downslope flow after loss of control over the sill crest in Knight Inlet due to strong tidal forcing. Arrows indicate velocity vectors derived from Doppler profiling.

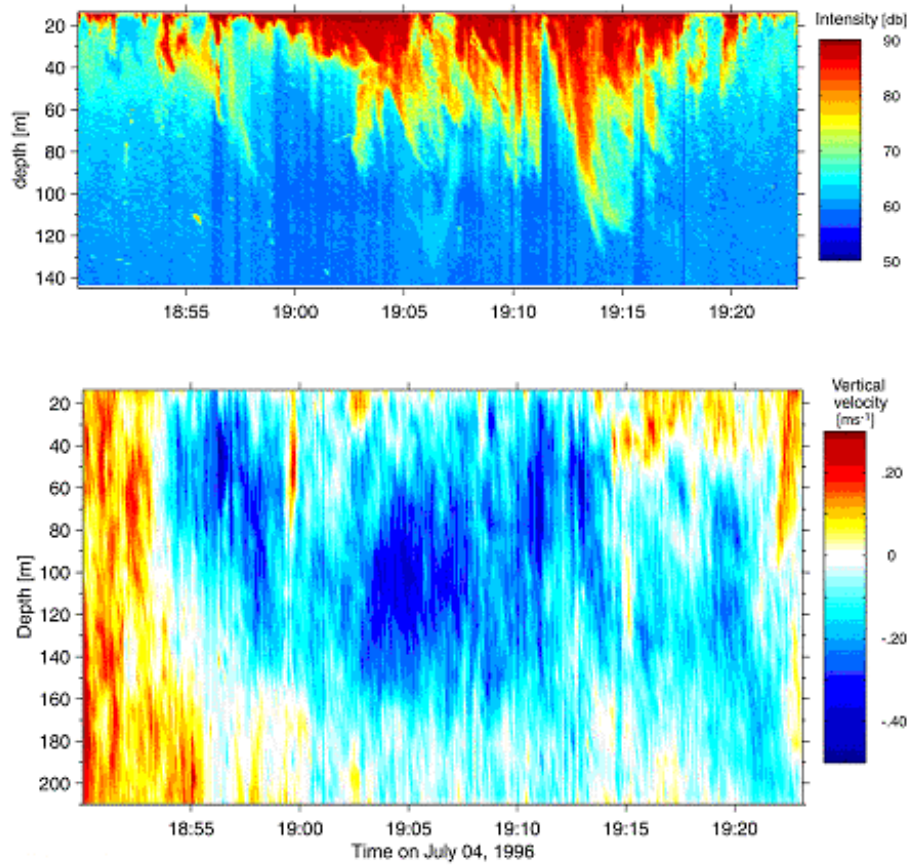


**Figure 2b** Normalized depth of lower layer (vertical axis) against normalized lower layer flow transport. Observations (points) compared with single layer reduced gravity theoretical predictions.





**Figure 3a** Aerial photograph showing the CGS VECTOR in a zone of intense turbulence and eddy intensification associated with the tilting of separated flow downstream of a headland.



**Figure 3b** Upper Panel: Echo-sounding from ship as it passes over area of intense turbulence, showing bubbles drawn down to 120m. Lower Panel: Vertical Doppler derived velocity field corresponding to upper panel, showing high downward speeds associated with convergence.

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